LUMINESCENCE DEVICE

FIELD OF THE INVENTION AND RELATED ART

The present invention relates to a

5   luminescence device for use in display apparatus,

illumination apparatus, etc., and more particularly to

a luminescence device utilizing a high

electroconductivity due to a self-alignment

characteristic of a liquid crystal compound.

10   An organic electroluminescence device

(hereinafter sometimes called an "organic EL device")

as a type of luminescence device, has been an object

of extensive research and development as a

luminescence device of high-speed responsiveness and

15   high efficiency.

Figures 1 and 2 are schematic sectional views

each illustrating a basic structure of an example of

organic EL device. Referring to Figures 1 and 2, such

organic EL devices include: a transparent substrate 1,

20   a transparent electrode 2, a metal electrode 3,

organic layer(s) 4, a luminescence layer 5, a hole-

transporting layer 6 and an electron-transporting

layer 7. Such a basic structure of an organic EL

device is disclosed in, e.g., Macromol. Symp. 125, pp.

25   1 - 48 (1977).

As shown in Figures 1 and 2, an organic EL

device generally has a structure including a laminate

comprising a plurality of organic layers 4 sandwiched
between a transparent electrode 2 and a metal
electrode 3 and disposed on a transparent substrate 1.

In the structure of Figure 1, the organic

5   layers 4 comprise a luminescence layer 5 and a hole-
transporting layer 6. The transparent electrode 2
comprises a material, such as ITO (indium tin oxide)
having a large work function, so as to ensure a good
hole injection characteristic from the transparent

10   electrode 2 to the hole-transporting layer 6. The
metal electrode 3 comprises a metal material having a
small work function, such as aluminum, magnesium or
alloys of these, so as to ensure a good election
injection characteristic to the organic layers 4. The

15   electrodes 2 and 3 may be formed in a thickness of 50
- 200 nm.

The luminescence layer 5 may for example
comprise an aluminum quinolynol complex (a
representative example of which is "Alq" having a

20   structure as shown below) showing an electron-
transporting characteristic and a luminescence
characteristic. The hole-transporting layer 6 may
comprise a material showing an electron-donating
characteristic, such as triphenyldiamine derivatives

25   (a representative example of which is "α-NPD" having a
structure as shown below):

Alq

5

α-NPD

10
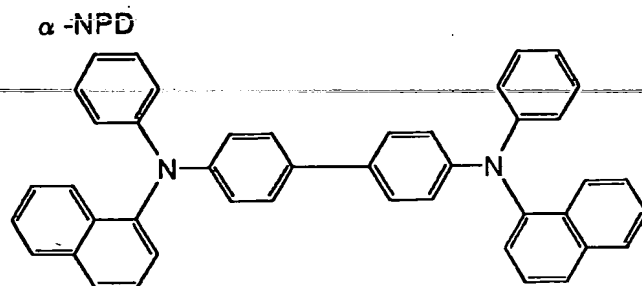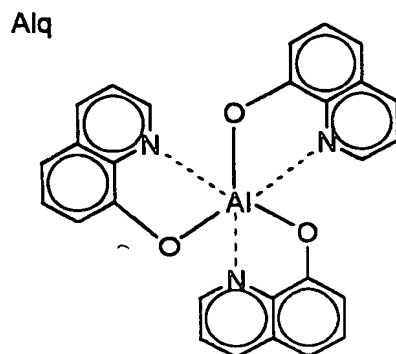
    The organic EL device of Figure 1 shows a

15 rectifying characteristic, and when a voltage is

applied between the metal electrode 3 as a cathode and

the transparent electrode 2 as an anode, electrons are

injected from the metal electrode 3 into the

luminescence layer 5, and holes are injected from the

20 transparent electrode 2. The holes and electrons

injected to the luminescence layer 5 are recombined in

the luminescence layer 5 to form excitons, which cause

luminescence. In this instance, the hole-transporting

layer 6 functions as a layer for blocking electrons to

25 provide a higher recombination efficiency at the

luminescence layer/hole-transporting layer boundary,

thereby providing an enhanced luminescence efficiency.

Further, in the structure of Figure 1, an electron-transporting layer 7 is disposed between the metal electrode 3 and the luminescence layer 5 in the structure of Figure 1. According to this structure,

5 the luminescence function is separated from the functions of both electron transportation and hole transportation, to provide a structure exhibiting more effective carrier blocking, thus realizing more efficient luminescence. The electron-transporting

10 layer 7 may comprise, e.g., an oxadiazole derivative.

The organic layers 4 comprise two or three organic layers and may have a thickness of 50 - 500 nm in total of the two or three layers.

In the above-mentioned organic EL devices,

15 the luminescence performance is critically determined by performance of injection of electrons and/or holes from the electrodes. The above-mentioned amorphous materials, such as Alq and αNPD are not believed to provide sufficient carrier injection performances in

20 view of the resultant electrode-organic layer boundaries.

Further, in the course of recent development of organic EL devices, devices utilizing phosphorescence from a triplet exciton instead of

25 fluorescence from a single exciton have been studied. This is discussed in, e.g., the following articles:

(1) "Improved energy transfer in electro-

phosphorescent device" (D.F. O'Brien, et al, Applied Physics Letters Vol. 74, No. 3, p. 422 (1999)); and

(2) "Very high-efficiency green organic light-emitting devices based on electro-phosphorescence"

5 (M.A. Baldo, et al, Applied Physics Letters Vol. 75, No. 1, p. 4 (1999)).

In the above articles, a structure including organic layers 4 of four layers as shown in Figure 3 is principally used. More specifically, the organic

10 layers 4 sequentially include, from the anode side, a hole-transporting layer 6, a luminescence layer 5, an exciton diffusion prevention layer 9 and an electron-transporting layer. As materials constituting the organic layers 4, in addition to Alq and α-NPD

15 mentioned above, there have been enumerated carrier-transporting materials, such as CBP (4,4'-N,N'-dicarbazole-biphenyl) and BPC (2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline), and phosphorescent compounds, such as PtOEP (platinum-octaethylporphyrin

20 complex) and Ir(ppy)$_3$ (irridium-phenylpyrimidine complex), respectively represented by the following structural formulae:
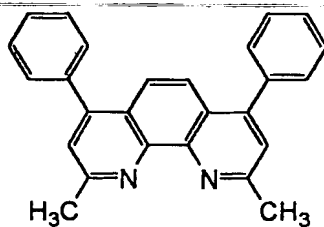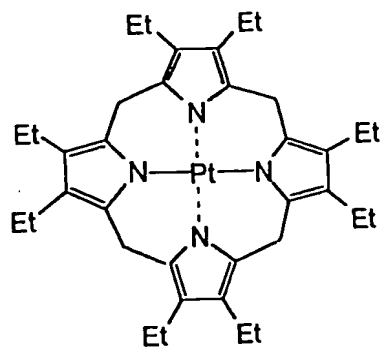
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CBP

5

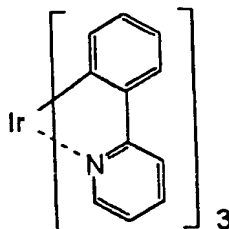BCP

10

PtOEP

Et   Et

Et   Et

Et   Et

Et   Et

15

20

Ir(ppy)₃

Ir
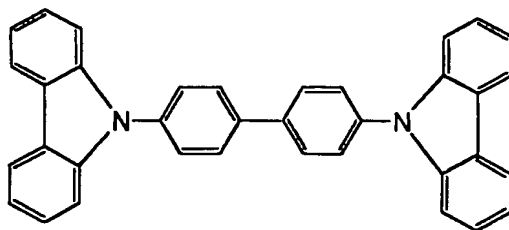
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The above-mentioned articles have reported structures, as exhibiting a high efficiency, including a hole-transporting layer 6 comprising α-NPD, an electron-transporting layer 7 comprising All, an

5 exciton diffusion-prevention layer 9 comprising BCP, and a luminescence layer 5 comprising CBP as a host and 6 mol. % of PtOEP or 6 wt. % of $Ir(ppy)_3$ as a phosphorescent compound.

A phosphorescent compound has been

10 particularly noted because it is expected to exhibit a high luminescence efficiency in principle. More specifically, excitons formed by carrier recombination comprise singlet excitons and triplet excitons in a probability ratio of 1:3. Conventional organic EL

15 devices have utilized fluorescence emitted by transition from a singlet exciton to the ground state as available luminescence, but the luminescence efficiency thereof is limited to at most ca. 25 % of generated excitons in principle. On the other hand,

20 if phosphorescence of excitons generated from triplets is utilized, an efficiency of at least three times is expected, and even an efficiency of 100 %, i.e., four times, can be expected in principle, if a transition owing to intersystem crossing between singlet and

25 triplet states is taken into account.

Devices utilizing luminescence from triplet states are also proposed in JP-A 11-329739 (entitled

"organic EL device and process for production thereof"), JP-A 11-256148 (entitled "luminescence material and organic EL device using same"), and JP-A 8-319482 (entitled "organic electroluminescence device", corr. to U.S. Patents Nos. 5,698,858 and 5,756,224).

In the case where the luminescence layer comprises a host material having a carrier-transporting function and a phosphorescent guest material, a process of phosphorescence attributable to triplet excitons may include unit processes as follows:

(1) transportation of electrons and holes within a luminescence layer,

(2) formation of host excitons,

(3) excitation energy transfer between host molecules,

(4) excitation energy transfer between the host to the guest,

(5) formation of guest triplet excitons, and

(5) phosphorescence.

Energy transfer in each unit process is caused by competition between various energy transfer and deactivation processes. For example, a host exciton, even if formed, can lose its energy by nonradiative deactivation prior to energy transfer to another host. Also in the process of energy transfer

from the host to the guest, a host-guest exciplex, when formed, can provide a deactivation process, thus failing to cause luminescence in some cases. Accordingly, the selection of a host material

5   determining an environmental condition surrounding a phosphorescent material is an important point for achieving an increased luminescence efficiency.

SUMMARY OF THE INVENTION

10   In view of the above-mentioned state of the prior art, a principal object of the present invention is to provide a luminescence device showing a higher luminescence efficiency.

According to the present invention, there is

15   provided a luminescence device, comprising a pair of electrodes, and at least one organic compound layer including an organic compound layer comprising a mixture of a liquid crystal compound and a phosphorescent compound.

20   These and other objects, features and advantages of the present invention will become more apparent upon a consideration of the following description of the preferred embodiments of the present invention taken in conjunction with the

25   accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1 to 4 are schematic sectional views each showing a basic structure of an organic EL device.

5   DESCRIPTION OF THE PREFERRED EMBODIMENTS

The luminescence device of the present invention is especially characterized by a luminescence layer comprising a host material and a phosphorescent guest material, wherein the host

10   material comprises a liquid crystal compound. The liquid crystal compound used in the present invention is a material having an electronic carrier-transporting function, which has been expected in recent years to provide an electron-transporting layer

15   or a luminescence layer showing high carrier-injection ability and high carrier-transporting ability. Herein, the electronic carrier-transporting function means an ability of moving electronic carriers, such as holes and electrons. As such a liquid crystal

20   compound having a high carrier-transporting function, it is possible to use a liquid crystal compound assuming a discotic phase or a smectic phase exhibiting a high degree of order.
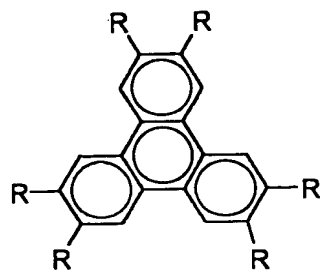
Examples of such a liquid crystal assuming a

25   discotic liquid crystal, i.e., a discotic liquid crystal, may include triphenylene-type liquid crystal compounds having structures as shown below (e.g., as

disclosed in Advanced Materials, 1996.8, No. 10).

<u>LC Compounds 1 to 5</u>

5

LC compound 1   R = -SC$_6$H$_{13}$

LC compound 2   R = -OC$_4$H$_9$
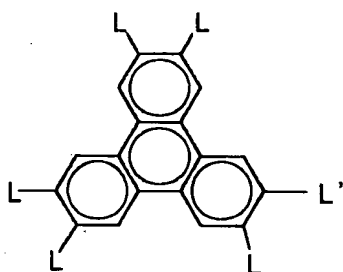
LC compound 3   R = -OC$_5$H$_{11}$

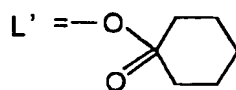LC compound 4   R = -OC$_6$H$_{13}$

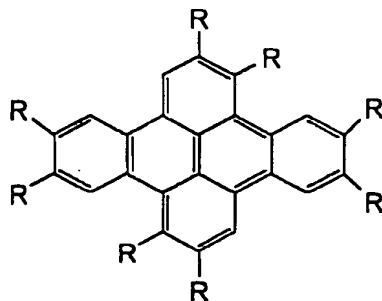LC compound 5   R = -OC$_4$H$_8$C$_2$F$_5$

10

<u>LC Compound 6</u>

15

L = -OC$_5$H$_{11}$

L' = -O

<u>LC Compound 7</u>

20

R = -OC$_5$H$_{11}$

25

The above-indicated LC Compounds 1 - 4 having side chains or substituents R of alkoxy groups $-OC_4H_9$, $-OC_5H_{11}$ and $-OC_6H_{13}$ and a thio-ether group $-SC_6H_{13}$ are known to exhibit a hole-transporting performance at a

5 high carrier mobility (on the order of 10^{-1} - 10^{-3} cm/Vs). These compounds exhibit a discotic columnar phase wherein disk-shaped liquid crystal molecules are aligned to form a columnar shape so that their triphenylene skeletons rich in π-electrons are

10 mutually superposed, thus exhibiting a good hole-transporting characteristic via the triphenylene group. LC Compound 5 shown above was developed by our research group and, because of polyfluorinated side chains, exhibits a discotic liquid crystal phase range

15 shifted to a lower temperature side and a lower ionization potential than the corresponding non-fluorinated compound. LC compound 7 has a dibenzopyrene skeleton and also exhibits a discotic columnar phase.
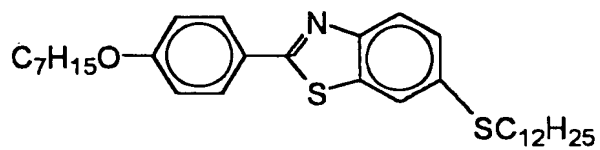
20 Other discotic liquid crystals may include those having skeletons of phthalocyanine derivatives, naphthalocyanine derivatives, truxene derivatives, hexabenzocolonene derivatives and benzoquinone derivatives.

25 Representative smectic liquid crystal materials may include those represented by the following structural formulae (as disclosed in Applied

Physics ("Ohyou Butsuri", Vol. 68, No. 1, p. 26 - (1999)).

LC Compound 8

5

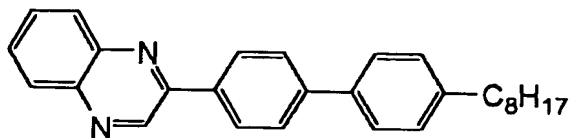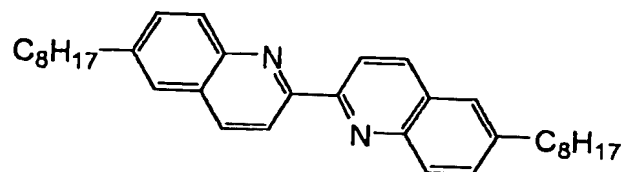$C_7H_{15}O$ —⟨benzene⟩— benzothiazole — $SC_{12}H_{25}$

LC Compound 9

10

C_4H_9O — naphthalene — ⟨benzene⟩ — C_8H_{17}

15   LC Compound 10

quinoxaline — ⟨benzene⟩ — ⟨benzene⟩ — C_8H_{17}

20

LC Compound 11

C_8H_{17} — quinoline — quinoline — C_8H_{17}

25
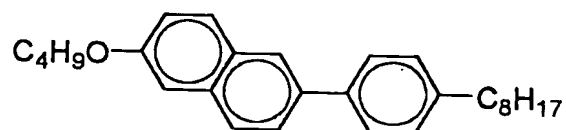
LC Compound 8 shown above classified as a phenylbenzothiazole derivative and showing smectic A phase has a hole-transporting characteristic. LC Compound 9 classified as a phenylnaphthalene

5   derivative shows smectic A phase and smectic E phase and a higher mobility in the smectic E phase of a higher order than the smectic A phase, and also exhibits bipolar carrier (i.e., hole and electron)-transporting characteristic. All the liquid crystal

10   compounds shown above exhibit a high mobility of 10^{-3} cm/V.s or higher.

Other liquid crystal compounds having a bar-shaped skeleton and showing a smectic liquid crystal phase may also be used.

15   It is preferred that the luminescence device of the present invention is used in a temperature range where the luminescence layer comprising a liquid crystal compound and a phospphorescent compound assumes a liquid crystal phase.

20   As specific examples of phosphorescent compounds used as a guest material for constituting the luminescence layer, it is possible to preferably use PtOEP or Ir(ppy)$_3$ as described hereinbefore, and it is particularly preferred to use a compound having

25   a planar molecular skeleton like PtOEP. Such a phosphorescent compound, when used in mixture with a liquid crystal compound to form a luminescence layer,

can provide a luminescence device having a high
luminescence efficiency. The organic layer structure
in the luminescence device can preferably assume any
one of those shown in Figures 1 to 4.

5   Now, the function of the liquid crystal .
compound used will be described in detail.

An amorphous material generally used in an
organic EL device passes a current with a carrier
injection as a rate-controlling step. In contrast

10   thereto, if a carrier injection layer comprising a
liquid crystal compound is formed in contact with an
electrode, the carrier injection-controlling state is
alleviated, and a bulk-controlling current is flowed
reflecting the bulk characteristic. This is

15   presumably because a liquid crystal compound has a π-
electron-conjugated plane close to a planar structure
and the π-electron-conjugated plane is aligned
parallel to the electrode surface to enhance the
interaction with the electrode and promotes the

20   carrier injection in contrast with an amorphous
material which generally has a massive structure so
that a π-electron-conjugated structure thereof in
charge of carrier injection cannot be aligned parallel
to the electrode surface.

25   Accordingly, in the case where a liquid
crystal compound is used in a carrier-transporting
layer, it becomes possible to utilize the carrier

transporting performance reflecting directly the bulk
performance thereof, thus exhibiting a carrier
injection performance exceeding that of a known
amorphous material.

5   Figure 4, for example, shows an example of EL
device organization utilizing a liquid crystal
compound for improved carrier injection performance,
proposed by our research group. For example, if a
hole-injection layer 8 comprising a triphenylene-based

10   liquid crystal compound is inserted, the hole
injection performance from a transparent electrode 2
to an organic layer 4 is improved, thereby providing
increased current density and luminescence at an
identical applied voltage than in the absence of such

15   a hole-injection layer 8.

Thus, a liquid crystal compound having a
carrier-transporting function exhibits, in summary:
[1] a high carrier mobility due to bulk self-
alignment, and

20   [2] a high carrier-injection characteristic due to
alignment of the π-electron-conjugated plane parallel
to the electron boundaries, which cannot be exhibited
by conventional amorphous materials.

The present invention is characterized by the

25   use of such a liquid crystal compound as a host
material of a luminescence layer. No study has been
made regarding energy transfer in the above-mentioned

unit processes (1) - (6) of the phosphorescence in the
case where a liquid crystal compound is used as the
host material. As a result of our study, it has been
found possible to realize an enhanced luminescence
efficiency if a material showing a liquid crystal
alignment state is used instead of a material showing
an amorphous state, thus arriving at the present
invention. The higher luminescence efficiency
attained by using a liquid crystal compound in the
present invention may be attributable to the following
mechanism.

The above-mentioned unit process of (3)
excitation energy transfer between host molecules in
the entire phosphorescence process is considered. It
is important to note the intermolecular energy
transfer of triplet excitons strongly contributing to
phosphorescence. Compared with a singlet exciton, a
triplet exciton has a very long life (of 1 μsec or
longer), during which the energy is transferred by
migration between molecules. It is considered that
the energy transfer by migration is more effectively
caused due to effective molecular interaction in a
liquid crystal compound having π-electron-conjugated
planes parallel to the electrode than in an amorphous
material including completely random molecular
alignment.

On the other hand, in the case of excessively

strong inter-molecular interaction, an excited
molecule and a ground-state molecule can form an
associated molecule (excimer), through which
deactivation is caused. A strong molecular

5   interaction is present between planar molecules like
skeletons (e.g., triphenylene skeletons) of a liquid
crystal compound, so that the deactivation through
excimer formation gave some concern but was not
serious. This is presumably partly because extensive

10   movement of long alkyl or alkoxy side chains providing
a mesomorphism to the liquid crystal compound
obstructs such excimer formation.

As a result of our study, it has been also
clarified that the energy transfer depends on

15   molecular interaction attributable to inter-molecular
overlap integral. This is because the mobility of a
liquid crystal compound depends on an intermolecular
overlap integral so that in the case of using liquid
crystal compounds having an identical skeleton, the

20   mobility is believed to reflect the magnitude of
overlap integral.

For example, the above-mentioned
triphenylene-type liquid crystal compounds showed the
following properties indicating that a closer plane

25   distance and a smaller distribution thereof provided
an increased π-electron overlap integral to result in
a higher mobility.

Table 1

Compound	L.C. Phase *1	Mobility *2 (cm^2/Vs)	Core plane distance *3 (nm)	Luminescence yield ratio *4 (-)
LC Compound 2	Dhc	1×10^{-2}	0.359	1
LC Compound 3	intermediate of Dhc and Dhd	3×10^{-3}	0.364	0.92
LC Compound 4	Dhd	7×10^{-4}	0.368	0.82

*1:   Dhc = discotic hexagonal disordered phase.

Dhd = discotic hexagonal ordered phase.

*2:   Measured by the time-of-flight method at a
liquid crystal layer thickness of 15 μm.

5   *3:   Measured by the X-ray diffraction method.

*4:   The luminescence yield ratio data are based
on values of luminescence intensity (integrated over
wavelengths) per unit current density measured based on
the structure of Example 3 described hereinafter and

10   using different liquid crystal compounds. The data in
Table 1 shows that a higher mobility resulted in a
higher luminescence yield.

From the above data, it is understood that a

15   liquid crystal compound exhibits a better performance
of energy transfer between host molecules.

Also regarding the phosphorescence unit
process of (4) excitation energy transfer between the
host and guest, a liquid crystal compound is

20   advantageously used as a host material. Excitation
energy transfer between different molecules includes a
singlet exciton transfer due to intermolecular bipolar
dipole interaction known as Foerster transfer, which
is a transfer process possibly occurring between

25   relatively remote molecules. On the other hand, a
triplet exciton energy transfer is caused by a Dexter
process as the Foerster transfer is based on spin-

forbidden transition. The Dexter process is caused by

electron exchange between adjacent molecules and

strongly depends on overlapping of molecules. With

respect to any guest molecule, a compound having a

5   skeleton of a π-electron planar structure, like a

liquid crystal compound, provides a preferred

molecular overlap compared with an amorphous molecule,

as a host molecule. Further, in the case where a

guest luminescence center material has a planar

10   molecular skeleton like PtOEP mentioned above, the

guest molecule causes a larger π-electron overlap with

such a host molecule like a liquid crystal compound,

thus causing effective energy transfer.

Also in this case, the formation of an

15   associated molecule (exciplex) of exciton and a

ground-state molecule is concerned, but the formation

of such a two-molecule associate is suppressed due to

influence of side chains and fluidity of a liquid

crystal compound. This has been confirmed by

20   effective energy transfer.

Also, the effect of energy level change of

the guest luminescence center under the influence of

the host, is not negligible. For example, in the case

of using Ir(ppy)$_3$ as a guest luminescence center

25   molecule, ^{3}MLCT* (triplet metal to ligand charge

transfer excited state) is desired as the lowest

triplet excitation state for high-efficiency

luminescence, but $^3\pi-\pi^*$ can occur in some cases. The
energy level of ^{3}MLCT* varies depending on the
viscosity of the host and becomes lower at a lower
host viscosity. Accordingly, in order to stabilize

5   the ^{3}MLCT* as the lowest excitation state, it is
preferred to use a liquid crystal compound showing a
fluidity and a lower viscosity than an amorphous
material.

Further, the exciton of a host molecule is

10   required to have a longer exciton life than the guest
and is desired to have a stable triplet state. For
example, triphenylene forming the skeleton of the
above-mentioned triphenylene-type liquid crystal
compound is a representative compound exhibiting

15   phosphorescence and has a relatively long triplet
life. In this way, it is preferred to use a liquid
crystal compound exhibiting phosphorescence.

As described above, a liquid crystal compound
is a material which provides an inter-molecular

20   interaction for energy transfer and movement, is less
liable to form a excited dimer associate adversely
affecting the energy transfer and is suitable for
effective triplet energy transfer and movement
promoting phosphorescence.

25   Because of a high luminescence efficiency,
the luminescence device of the present invention
realizes a higher luminance luminescence or provides

an identical luminance at a lower voltage.

[Examples]

Example 1

A 70 nm-thick ITO film was formed by
sputtering on a glass substrate to provide a
transparent electrode. On the other hand, a 100 nm-
thick aluminum (Al) film was formed on another glass
substrate and patterned to provide metal electrodes.
These glass substrates were disposed with their
electrodes facing each other and applied to each other
with 1 μm-dia. silica beads dispersed therebetween to
form a blank cell.

Separately, LC Compound 4 listed above as a
triphenyl-type liquid crystal compound was mixed with
5 mol. % of PtOEP (also listed above) as a
phosphorescent compound in chloroform, followed by
removal by evaporation of the chloroform, to prepare a
liquid crystal composition. The liquid crystal
composition was injected into the above-prepared cell
at its isotropic temperature of 110 ^{o}C under a vacuum
of 1.3×10^{-2} Pa, to prepare a luminescence device.

As a result of a microscopic observation, the
liquid crystal composition exhibited Dhd phase
(discotic hexagonal ordered phase) in a temperature
range of ca. 70 ^{o}C to ca. 98 ^{o}C on temperature
increase. The luminescence device was subjected to
voltage application of 120 volts between the

transparent electrode (anode) and the metal electrodes
(cathode) at 30 ^oC (below liquid crystal phase
temperature) and 70 ^oC (liquid crystal phase
temperature), respectively, whereby red luminescence

5   attributable to PtOEP was confirmed at the respective
temperatures. In response to a temperature change
from 30 ^oC to 70 ^oC, the current was increased to 5
times. A luminescence yield ratio (at 30 ^oC/70 ^oC) of
1:4 was attained based on a definition of luminescence

10   yield = luminance/passed current value, thus
exhibiting effective energy transfer by the use of a
liquid crystal compound.

Example 2

     A luminescence device was prepared in the

15   same manner as in Example 1 except for using LC
Compound 9 (also listed above) instead of LC Compound
4 and using Ir(ppy)$_3$ (also listed above) instead of
PtOEP to prepare a liquid crystal composition. The
liquid crystal composition assumed SmE phase at 66 ^oC,

20   SmA phase at 122 ^oC and isotropic (Iso) phase at 132
^oC, respectively, on temperature increase.

     The luminescence device was subjected to
voltage application of 100 volts or higher at 30 ^oC
and 70 ^oC (SmE phase), respectively, whereby green

25   luminescence attributable to Ir(ppy)$_3$ was confirmed at
the respective temperatures. The luminescence yield
ratio was 1:2.6 (at 30 ^oC/70 ^oC), thus exhibiting

effective energy transfer by the use of a liquid crystal compound.

Example 3

A luminescence device having a laminate
5   structure as shown in Figure 3 was prepared.

More specifically, a 70 nm-thick ITO film was formed by sputtering on a glass substrate 1 to provide a transparent electrode 2 and, at a vacuum of 1.3×10^{-4} Pa on an average, was further subjected to successive
10   vacuum deposition of four organic layers, i.e., a 30 nm-thick hole-transporting layer 6 of α-NPD, a 30 nm-thick luminescence layer 5 of a liquid crystal composition comprising a 95:5 (by volume) mixture of LC Compound 4 and $Ir(ppy)_3$, a 30 nm-thick exciton
15   diffusion-preventing layer 9 of BPC (2,9-dimethyl-4,7'-diphenyl-1,10-phenanthroline) and a 30 nm-thick electron-transporting layer 7 of Alq. The vapor deposition of the organic layers 6, 5, 9 and 7 was performed by placing each organic in an amount of ca.
20   100 mg on a molybdenum-made boat and by resistance heating to provide a desired vapor deposition rate. For the formation of the luminescence layer 5, LC Compound 4 and $Ir(ppy)_3$ was co-vaporized at film growth rates of 0.15 nm/sec and 0.075 nm/sec.,
25   respectively, based on the results of preliminary film growth speed measurements by means of a film thickness meter using a quartz vibrator element.

Above the organic layers, an Al alloy containing 1.8 mol. % of Li was vapor-deposited in a thickness of 10 nm and then Al metal was vapor-deposited in 150 nm to provide a cathode 3. The

5   inclusion of the Li metal at the cathode boundary promotes the electron injection because of a small work function thereof.

The thus-prepared luminescence device was heated to 70 °C (liquid crystal phase temperature of

10   the above-liquid crystal composition) and subjected to voltage application between the electrodes. As a result, when voltages were applied between the electrodes with the ITO electrode 2 as the anode, a good rectifying characteristic showing a good

15   conductivity was confirmed, and green luminescence attributable to Ir(ppy)$_3$ was confirmed at a voltage of 5 volts or larger.

Comparative Example 1

A luminescence device was prepared in the

20   same manner as in Example 3 except for using a composition including hexamethoxytriphenylene having no liquid crystal phase instead of LC Compound 4 used in the liquid crystal composition of Example 3. As a result of voltage application, the resultant device of

25   Comparative Example 1 exhibited a luminescence yield ratio of 1/3 with respect to that of Example 3, thus exhibiting an improved luminescence efficiency

obtained by using LC Compound 4 as a host compound in Example 3 instead of hexamethoxytriphenylene used in Comparative Example 1.

Example 4

5   A luminescence device was prepared in the same manner as in Example 1 except for using $Ir(ppy)_3$ instead of PtOEP. The resultant luminescence device exhibited a luminescence yield (luminance/current) ratio at identical temperature (70 $^{\circ}$C) and voltage

10   (120 volts) of 1/0.8 with respect to the device of Example 1, thus showing a higher luminescence yield in this Example 4. However, with respect to a total luminescence intensity (integral of luminescence intensity over spectral wavelengths), the device of

15   Example 1 exhibited 4 times as large as that of the device of Example 4. The difference is because the above-mentioned luminescence yield value is based on "luminance" depending on human visual sensitivity which is 5 times as large at 510 nm (luminescence

20   wavelength of $Ir(ppy)_3$) as at 650 nm (luminescence wavelength of PtOEP), so that the above result rather means that the device of Example 1 showed a higher efficiency of conversion to photo-energy, thus showing a better energy transfer caused by PtOEP having a

25   planar molecular skeleton as a host compound.

       As described above, the present invention provides a luminescence device showing a higher

luminescence efficiency, which is applicable to a
product requiring energy economization or higher
luminance. More specifically, the luminescence device
is applicable to a display apparatus, an illumination

5   apparatus, a printer light source or a backlight for a
liquid crystal display apparatus. As for a display
apparatus, it allows a flat panel display which is
light in weight and provides a highly recognizable
display at a low energy consumption. As a printer

10   light source, the luminescence device of the present
invention can be used instead of a laser light source
of a laser beam printer and may be disposed in an
independently addressable matrix arrangement to effect
desired exposure on a photosensitive drum for image

15   formation. The use of the luminescence device of the
present invention is effective for providing such an
illumination device or a backlight at a remarkably
reduced apparatus volume and a minimal energy
consumption.

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